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Modular Building Unit and Method of Assembly

DESCRIPTION

The invention relates to modular building units for use in the construction of largely prefabricated offices, hotels and apartment blocks, and buildings of a similar general nature. Such modular building units are box-like structures which can be manufactured and fitted-out off-site and then transported to a construction site for final assembly to form the internal rooms of a building.

Background Art

Particularly in the construction of hotels, apartments and student accommodation it is known to construct the buildings from lightweight building modules each of which is a skeletal steel shell formed from lightweight structural steel sections welded into a box-like structure and lined with boarding such as plasterboard, plywood or oriented strand board (OSB). Each building module is made initially as such a lined shell, and is then fitted-out to the desired standard of internal decoration in a factory before being transported to the final building site for incorporation into a building.

GB-A-2334045 discloses one method of construction of such a building module. A number of rectangular or otherwise identically shaped frame members are formed and aligned in mutually spaced parallel relationship as the ribs of the final skeletal shell. Then they are connected together by multiple cross-braces which lie on the inside of the resulting shell. Wall panels are secured to the cross-braces. Floor and ceiling panels are added, as are end panels, and the module is finished to its final standard of internal decoration.

One inevitable characteristic of the module of GB-A-2334045 is that the entire module is made and fitted-out in a single factory. The initial fabrication step of setting out the pre-formed row of rectangular frame members and joining them together with the horizontal cross-braces creates a skeletal steel box-like structure. Once this skeleton is welded into its final box-like shape or shell the transportation of

that shell becomes a major expense, with a separate lorry or low-loader being needed to move each such skeletal shell out of the factory. Therefore the shells are lined and fitted out in the same premises which may be a considerable distance from the site of the final building to be erected. The completely fitted-out modules are then transported, generally by road, to the final building site for erection of the hotel or apartment block to be built. This carries with it considerable potential transport costs.

Another characteristic of the module of GB-A-2334045 is that a direct thermal path is provided from the internal panelling to the frame members through the cross-braces. A fire in the finished building therefore has a relatively short heat path before it causes distortion of the ribs or frame members which are the structural uprights of the finished building. This is a major concern because the steel of the frame members and cross-braces is lightweight steel framing and can readily distort in the event of thermal overload. The maximum height of a building made from modules in accordance with GB-A-2334045 is therefore a relatively small number of storeys, typically about four or five.

It is an object of the invention to provide a building module and a method of building using such modules which both reduces cost and improves the fire resistance of the building as compared with the use of similar grade materials in the known modular building methods. By improving the fire resistance of each module the invention permits the erection of higher rise blocks of rooms using the building modules of the invention.

The Invention

The invention comprises a modular building unit as specified in claims 1 to 11 herein, and a method of fabricating a modular building unit as specified in claim 12 herein.

The building modules according to the invention can be stacked in a horizontal and vertical array using edge location means as described and claimed in copending Patent Application No W068005 filed herewith, and linked together horizontally and vertically as described and claimed in W068006 filed herewith, to form buildings 20

or more storeys high. If desired the outside of such buildings can be cross-braced using diagonal structural members which may themselves be made from lightweight cold-formed steel section. Such cross-braces are known *per se*. That may however be unnecessary if the cross-braces are located diagonally rather than horizontally.

The lightweight structural steel sections used as the structural uprights in the modular building units of the invention have excellent tensile stress resistance but relatively poor compression resistance. Additional tensile stress resistance may however be provided by incorporating a rod or tube or cable within selected ones of the structural uprights. If rods or tubes are used, then each preferably extends the full height of the wall lattice framework, which is the height of one full storey of the erected building, and preferably terminates at each of its ends with means for connecting that rod or tube to aligned rods or tubes of the vertically adjacent storeys. That effectively ties together the successive storeys of the finished building in the vertical direction. If desired similar rod, tube or cable reinforcement can extend horizontally from end to end or side to side of the building module through the wall lattice framework or through the cross-beams, for tying together adjacent modules of the erected building in the horizontal plane.

Particularly for the construction of buildings more than 20 storeys high, or buildings that are susceptible to lateral shear forces caused by side winds, the external walls of the buildings are preferably reinforced by highly compression-resistant columns either included within the wall thickness of the pre-formed rectangular frame units or secured to the outsides of the individual modules or stacks of modules.

A preferred form of compression-resistant column is one which comprises a hollow tubular steel section filled with concrete, preferably with concrete that is reinforced with steel rods. The steel section may be hot-formed, for example as rectangular or circular section tubular steel stock, or may be made from lightweight cold-formed steel similar to the steel used in the remainder of the building module. Individual compression-resistant columns may be the height of one single modular building unit or may be the height of two or more storeys in the final building. If the former then

the compression-resistant columns may be incorporated into the individual wall lattice frameworks. Otherwise they may be attached to the outside of the assembled building module or to the outside of the assembled building. If desired the compression-resistant columns may be pre-cast and optionally reinforced concrete columns each of which is received in a void established between two or more mutually spaced parallel structural uprights, and the wall lattice framework built around those columns.

The invention also provides a method of fabricating the modular building unit of the invention when divided in a cost-effective manner between two manufacturing sites as specified in claim 17 herein. The side and end wall lattice frameworks are made and assembled at the first site, and also at the first site it will generally be convenient to manufacture all other cold-formed metalwork, including the cross-beams and any other formed metalwork to be used in the final assembly process. This means that all of the apparatus for cold-forming the structural members from lightweight steel can be provided at that first site. Also, the assembly of the wall lattice frameworks, which is a skilled operation requiring a high degree of precision, is suitably carried out at that first site. The assembly of the wall lattice frameworks is generally achieved by placing the individual structural formed steel members in an assembly jig, and then welding the components together by spot welding, seam welding or plug welding. The end product of that first manufacturing site is therefore a series of essentially flat wall lattice frameworks and optionally a series of essentially linear structural members such as the cross-beams, all of which can be loaded flat onto a lorry or railway truck, enabling the components of several modular building units to be loaded together onto a single lorry or truck. From the first site, those components are then transported to the second manufacturing site, which would typically be a regional site relatively close to the area in which the final building is to be erected from a number of assembled modules. At the second site, the wall lattice frameworks are assembled with the cross-beams to form the shell, and the shell is lined and fitted-out. Movement of the shell from the second site does require a single lorry or low-loader to transport each individual building module to the final building site for erection into a building, but by strategic use of regional assembly sites, the entire operation can be made much more economical than the assembly method of GB-A-2334045 which

requires the assembled units to be transported from a single manufacturing and assembly site where all of the precision work as well as the non-precision work of assembly and fitting-out is performed.

Preferably both the structural uprights and the cross-beams are of C-section. As is well known, such a section comprises a back face, two side faces and two front faces. Added strength can be provided by including one or more swages in one or more of the back, side and front faces, and the strength can if desired be further increased by including an inturned flange on one or both of the front faces. Even greater strength can be created by sleeving together two C-sections, one of which is swaged and the other of which is unswaged or swaged in the opposite direction, so that the assembly of the two C-sections creates a box structure with one or more continuous box channels running longitudinally of the final composite section.

The spur members which extend from the wall lattice frameworks may be T-shaped in plan view, each comprising two limbs of which one sits inside the C-section of the associated structural upright and the other extends transversely therefrom as a spur to receive an end of an associated cross-beam which is sleeved into or around that spur prior to being welded thereto.

The structural uprights, the cross beams and even the cross-braces are however preferably structural building elements formed from cold-rolled steel with sections as described and claimed in copending Patent Application No W068007 and as specified in claim 9 herein. Such sections are based generally on a C-section profile but with the maximum use of large diameter curves in place of the conventional flat faces. These sections are referred to herein as multi-curve C-section profiles. W068007 also discloses connectors suitable for joining together such multi-curve C-section profiled building elements into a lattice framework such as would be used according to this invention. In a typical lattice framework using only multi-curve C-section profiled structural uprights, cross-beams and cross-braces, the cross-braces would be in short lengths, each spanning only a single gap between adjacent structural uprights and connected to the structural uprights by T-connectors or K-connectors according to

W068007. Alternatively the cross-braces could be wider than the structural uprights, with the latter passing completely through oval slots stamped into the cross-braces during fabrication. Welds would be needed to secure the joints and make the lattice framework rigid.

The cold-formed steel resilient bars which connect the wall panels to the cross-braces are preferably Z-section profiles of which both formed angles are obtuse. One longitudinal edge portion of such a Z-section is a flange which is secured to thecross-braces, preferably down a vertical line of fixing points midway between adjacent structural uprights. The wall panels of the internal cladding are secured to the opposite longitudinal edge portion of the Z-section, which is also formed as an edge flange. The fixing means for the wall panels to the resilient bars may be any convenient mounting method, such as self-tapping screws. The two obtuse angles of the preferred Z-section shape provides resilience to the mounting of the internal cladding on the interior of the shell, that resilience being sufficient to reduce the sound transmission between the wall panels and the shell. Nowhere do the wall panels contact the structural uprights or the cross-braces, because they are held clear by the resilient bars. There is therefore no direct sound transmission from the wall panels to the structural uprights and, much more importantly, an extended heat path is provided between the wall panels and the structural uprights, passing first through the resilient bars to the cross-braces and then longitudinally of the cross-braces before they in turn are connected to the structural uprights. This extended heat path provides excellent thermal protection for the structural uprights in the event of a fire within the modular building unit. Preferably the wall panels used as internal cladding on the interior of the shell comprise two thicknesses of plaster board for even greater acoustic and thermal insulation.

The internal cladding to the interior of the shell also comprises floor and ceiling panels. Preferably additional external panels of floor panel thickness and strength are applied over the top of the shell. The latter means that when the modular building units are being assembled into a building, those additional external panels applied

over the top of the shell can take the weight of the workforce assembling the building, without the need for scaffolding or walking boards.

Drawings:

Figure 1 is a schematic illustrating the drawing convention of Figures 2a to 2e;

Figures 2a and 2b are elevations of the skeletal structures of two side wall lattice frameworks of a modular building unit according to the invention;

Figures 2c and 2d are elevations of the skeletal structures of two end wall lattice frameworks of the modular building unit;

Figure 2e is a plan view of the floor and ceiling joists of the modular building unit;

Figures 3 to 8 are sections taken along the sectional planes 3-3 to 8-8 respectively of Figures 2c, 2d and 2b;

Figures 9 to 12 are enlarged sectional details of the zones indicated 9 to 12 respectively of Figure 2e;

Figure 13 is a plan view of a piece of sheet steel blank which is folded to fabricate a first part of a spur member for securing the cross-beams to the wall lattice frameworks, with the intended fold lines being shown in broken line;

Figure 14 is a perspective view of the blank of Figure 13 folded into its final shape;

Figure 15 is a perspective view corresponding to Figure 14 but with a reinforcing plate added;

Figure 16 is a perspective view corresponding to Figure 15 but with two vertical C-channels added to develop a generally T-shaped plan view outline to the spur member;

Figure 17 is a perspective view of an alternative design of spur member;

Figures 18a to 18j are alternative C-sections that can be used for the structural uprights;

Figures 18k to 18n are alternative multi-curve C-section profiles as disclosed in W068007;

Figure 19 illustrates the section of across-brace for use with the C-sections of Figures 18a to 18j;

Figure 20 illustrates the section of a steel resilient bar to support the wall panels and hold them away from the structural uprights;

Figure 21 is a vertical section through a compression-resistant column for use in the erection of a tall building from modules according to the invention;
Figure 22 is a horizontal section through two structural uprights straddling a pre-cast reinforced concrete compression-resistant column to be used as an alternative to that of Figure 21; and
Figure 23 is a side elevation of a preferred lattice framework using structural uprights and cross-braces with the section shown in Figure 18k.

Referring first to Figures 1 and 2, the modular building unit of the invention is made by first constructing two side wall lattice frameworks as seen in Figures 2a and 2b, and two end wall lattice frameworks as seen in Figures 2c and 2d. Each such lattice framework comprises an array of mutually parallel spaced structural uprights 20 secured together by horizontal cross-braces22. The structural uprights 20 are cold-formed lightweight structural steel C-sections which can have any of the general profiles shown in Figures 18a to 18j. In Figures 18a to 18h, the C-section is shown either unswaged (Figure 18a) or with one or more swages 23 formed in the back 20a, side 20b or front 20c faces of the section. Figures 18e, 18f, 18g and 18h show how the C-section includes an inturned flange 24 on each of the front faces 20c of the section. Figures 18i and 18j show how the C-section can be further reinforced by the inclusion of additional C-sections to create closed box sections for additional strength.

For structural uprights shaped as in Figures 18a to 18j, the cross-braces 22 are of top hat section, as shown in Figure 19, and are spot welded or plug welded to the rear of the structural uprights 20 as viewed in Figures 2a to 2d. For increased rigidity, short spacer sections 26 of similar section can be positioned between adjacent structural uprights 20, and spot welded to the cross-braces 22.

Figures 18k to 18n show how the structural uprights may have a multi-curve C-section profile as described and claimed in W068007, in which case the cross-braces and cross-beams may also have any of the same general profiles.

Extending vertically down each side and end wall lattice structure and secured to the cross-braces 22 either directly or through the spacer members 26 are a vertical array of cold-formed steel resilient bars 28 each of which has a Z-section with obtuse angles as illustrated in Figure 20.

Extending laterally from each structural upright 20 is a pair of spur members 30 and 32, as shown in Figures 8 and 7 respectively. The spur members 32 are of different sizes to correspond to the sizes of the corresponding cross-beams at floor and ceiling height, but each is constructed as shown in Figures 13 to 16. Figure 13 shows a blank 34 of sheet steel which is bent along the broken lines into the general conformation shown in Figure 14. That shape is then fixed against distortion by spot welding into position a reinforcing plate 36 as shown in Figure 15, the lines of the spot welds being shown by a rows of crosses in Figure 15. Finally a pair of vertical C-section channels are spot welded along the vertical edge as shown in Figure 16, to create a general plan view which is T-shaped. The cross bar of the T, defined by the two C-sections 38, is received in the recesses of the structural uprights 20 in the same positions as the reinforcing C-sections 25 which are shown in Figures 18i and 18j, leaving the stem of the T jutting out transversely as a spur 30 or 32. Onto or into each projecting spur member 30, 32 is sleeved a cross-beam 40 of the floor or roof of the module, as illustrated in Figure 2e. Reinforcing cross-members 42 may be welded in place as required, for greater structural rigidity.

Figure 17 shows an alternative construction for the spur members 30,32. A single piece of C-section channel 44 is provided with a cap 42 of top hat section, the two being welded together with spot welding or plug welding. The top hat section 42 forms the bar of the resulting T-section spur member, and is received in the C-section of the structural uprights. The C-section 40 projects as the spur.

If the structural uprights and cross-beams have the profiles of Figures 18k to 18n, the spur members are connected as described in my copending Patent Applkication No W068007.

Once the skeletal shell has been assembled as described above, it is lined for example with plasterboard 44 as shown in Figures 3 and 4. Preferably two sheets of plasterboard 44 are used, on both the walls and the ceiling. Flooring 46 is also added (see Figure 4) and may be for example plywood, chipboard or OSB panels.

The connection of the plasterboard cladding 44 to the skeletal shell is through the steel resilient bars 28, which are sized such as to hold the plasterboard wall panels 44 clear of the structural uprights 20 as shown in Figures 3 and 4. The spacing is there illustrated as being extremely small, but even a small spacing does establish acoustic insulation together with a long and convoluted heat path from the plasterboard wall panels 44 to the structural uprights 20, as any heat resulting, for example, from an internal fire in the finished module has to pass laterally across the resilient bars 28 to the cross-braces 22, and then longitudinally along those cross-braces 22 to the structural uprights 20.

After the internal cladding has been secured in position as described, the building module can be completely fitted out in a factory before being transported to a building site where it is lifted into position alongside or on top of other similar modules, to create the finished building. Door and window final fittings, together with electrical and plumbing connections, are incorporated into each modular building unit before the unit is assembled with others as a building, then all that is necessary is to connect in those services and finish the building with a final facing skin which could be of brick or timber, to complete a fully internally decorated building.

Other details of the structure are apparent from Figures 9 to 12. Elements of a doorframe 50 are shown in Figure 9, and comprise studs consisting of an LC-section with an insert SC-section. Figure 10 shows a detail of corner studding. Structural uprights 52 are provided at the corners, each consisting of an LC-section with an inset SC-section. Figures 11 and 12 show how a greater structural strength is obtained on an outside wall by creating the outside end wall as a sandwich of a first array of structural uprights 20 connected together by cross-braces 22, and attached to the outside of that a second array of structural uprights 20' connected together with cross-

braces 22'. Externally, the module is completed with a bottom angle 54 and a top angle 56 to finish the corners, and internally with a bottom angle 58 and a top angle 60, all as shown in Figures 3 and 4.

In practice, the side and end wall lattice frameworks of Figures 2a to 2d are created on site in a first factory. If desired the spur members may be welded into position at that initial assembly site; or alternatively they may be provided to be slotted into place and welded into position at a second, less skilled, assembly site provided that the side and end wall lattice frameworks are provided with adequate location means to enable those spur members to be placed into a fully located end position before being welded in place. The essentially flat sections are then transported, by road or by rail, to that second site which is a regional site where they are built up into the finished module. First of all the two side wall latticed frameworks are connected one to the other by means of the cross-beams 30 and 32 at floor and ceiling height. Then the end wall lattice frameworks are presented up and welded into position. Next, the internal cladding is secured in position and preferably an additional sheet of external roof cladding is fixed over the roof of the module. The roof cladding may for example be OSB board of full flooring strength. Finally the interior of the module is painted and decorated to a final desired standard, including if necessary carpets and general fixtures such as fixed cupboards, before the finished module is moved from the second assembly site to the final building site.

Stacking of adjacent modules, and securing them together, is as described and claimed in my other three Patent Applications, W068005, W068006 and W068007, filed herewith. The modules as already described may be stacked and assembled into buildings up to twenty storeys high. However to construct taller buildings, or buildings which are subject to severe lateral stresses by virtue of either their location in a windy environment or their tall narrow geometry, it may be desirable to strengthen the outside walls using diagonal cross-braces or compression-resistant columns. The compression-resistant columns may be built into the walls of the pre-formed rectangular frame units, or may be secured to the outside of the individual modules or stacks of modules. In the former case the structural uprights would be

made the same height as the individual walls of the building units; in the latter case they might be the height of a single storey of the building or the height of two or more storeys. Figure 21 illustrates one form of compression-resistant column made by filling a tubular metal column 62 with concrete 63. The steel upright 62 may be formed from lightweight cold-formed steel section. The concrete fill 63 is formed into a domed nib 64 at the top, with a corresponding domed indent 65 at the bottom. When the resulting columns are placed one above the other to provide outer reinforcement for the finished building, then the nib 64 of each column engages in the corresponding recess 65 of the corresponding column of the storey immediately above, for positive location. Figure 21 also shows the provision of steel reinforcing bars 66 which add more structural strength to the compression resistant columns. If the columns are not built into the walls of the individual modules, then they may be secured to the outside walls, for example by welding.

Figure 22 shows how the compression-resistant columns may be built into the wall lattice framework. A pre-cast column 71 of reinforced concrete is provided, to extend the height of the wall lattice framework. The top and bottom may be provided with a nib and indent corresponding to those numbered 64 and 65 in Figure 21. The column 70 is shaped to lie between two structural uprights 20 each having the profile shown in Figure 18n, and steel straps 71 are welded to the outside of the uprights 20 to hold the assembly together. That reinforced composite structural upright may then be assembled into a wall lattice framework as described elsewhere in this specification.

Figure 23 illustrates a highly preferred wall lattice framework for incorporation into a building module according to the invention. The structural uprights 20 and cross-braces 22 have the profile of any of Figures 18k to 18n. The cross-braces 22 are connected diagonally, in a triangulation pattern for maximum strength. Each cross-brace 22 is connected to its associated structural uprights 20 and to the adjacent cross-brace 22 by a pair of pressed steel plates 72 positioned one on the outsid eand one on the inside of the wall lattice framework and welded to the uprights 20 and cross-braces 22. Chain-dotted lines 73 indicate the lines of connection of the steel resilient bars 28.

The individual building modules made up as described need not be rectangular in plan view. Any plan shape can be accommodated. Trapezoidal modules can be places together to create either straight or curved buildings. The modules can include features such as balconies to lie on the outside wall of the finished building. The walls do not even have to be straight, as it can be appreciated from Figure 23 that a curved wall can easily be constructed, for use according to this invention, from the multi-curve C-section profiled structural uprights and cross-braces of my Patent Application No W068007.